sixteen species of Coluber, and three of the genus Boa, which have these lateral orifices; that they have not as yet been discovered in the genus Anguis; and that in general it appears that only venomous snakes have this distinctive character.

From Mr. Home's description and remarks, we learn that these orifices do not lead to the nostril or to the ear, but to a distinct bag of a rounded form, there being within the skull a hollow of the same shape, surrounded by bone, which seems purely intended to receive it. This cavity is described as resembling a cup, formed by the bones of the skull and those of the upper jaw, and not unlike the orbit. The bags bear a relative proportion to the size of the snake; they are, like the eyelids, lined with a cuticle, which forms the transparent cornea, making a part of the outer cuticle; both which, it seems, are shed at the same time.

Mr. Home proceeds next to a description of similar bags in the deer and antelope kinds, which were by some thought to be lachrymal glands or ducts. On close examination, however, it is found that these bags have a secretion of their own, and that there is no reason for thinking that tears ever pass into them, the passage into the nose being unusually free, and the orifices of the bags in general unfavourably situated for the reception of the tears. The use to which the fluid secreted in these bags is applied, is as yet unknown. In the snake this apparatus has that position which seems best adapted to pour out the fluid upon the cornea when the head of the snake is in an erect position.

An Enquiry concerning the Nature of Heat, and the Mode of its Communication. By Benjamin Count of Rumford, *V.P.R.S. Foreign Associate of the National Institute of France, &c.* Read February 2, 1804. [*Phil. Trans.* 1804, *p.* 77.]

The importance of the investigation here entered into,—inasmuch as it applies to most of the operations of nature as well as art,—appears so manifest, that we shall not recapitulate what the author advances on that subject. Before he proceeds to the detail of his experiments for the purpose of computing the emissions of heat from various bodies under a variety of circumstances, he finds it necessary to premise a minute description of the principal part of the apparatus he contrived for his purpose. This instrument consists of a hollow cylindrical vessel of brass, four inches long, and as many in diameter. It is closed at both ends; but has at one end a cylindrical neck about eight-tenths of an inch in diameter, by which it is occasionally filled with water of different temperatures, and through which also a thermometer, constructed for the purpose, is occasionally introduced, in order to ascertain the changes of temperature in the fluid. As it was in the first instance only meant to observe the quantity of heat that escapes through the sides of the vessel, two boxes were contrived, filled and covered with non-conducting substances, such as eider-down, fur, &c., which were fitted to the two ends or flat surfaces of

the cylinder. Six of these instruments, with proper stands, and auxiliary implements of obvious construction, were prepared for the sake of comparative experiments.

A previous trial was made with two of the cylinders, the vertical polished sides of the one being naked, and those of the other covered with one thickness of fine white Irish linen, strained over the metallic surface. Here it was found, contrary to expectation, that in a certain space of time the covered cylinder had lost considerably more heat than the naked one.

In reflecting on this experiment it occurred to the author, that in order to insure the accuracy of the comparison between experiments made at different times and at different places, it would be necessary to fix on some particular interval of the scale of the thermometer above the temperature of the air by which the instrument is surrounded. He therefore determined that all experiments should begin at the temperature of 50°, and end at 40° above that of the surrounding atmosphere, an interval of 10° appearing to him sufficient for the purpose of his investigation. Finding also that most experiments would take up several hours, during which he could often not be present to observe the thermometer at the different points which ought to be ascertained, and observing that the rate of cooling of hot bodies afforded a pretty regular progression, he determined to investigate this rate more minutely, with a view to obtain the means of introducing such interpolations as would complete the series of observations. Accordingly, on a given line, on which were set off the times of cooling, he applied ordinates representing the different temperatures corresponding to those times; and having joined the opposite terminations of these ordinates, he had the satisfaction to find that this latter connecting line was in fact the logarithmic curve, by means of which he would be enabled to supply by computation any intermediate points which happened to have been neglected during the observation. The problem according to which these interpolations are to be computed, is given at full length.

These previous precautions and expedients having been fully stated, the author proceeds next to the enumeration of his long series of experiments, the first of which is merely the comparison, which has already been mentioned above, between the naked and the covered cylinders. The result was, that the former was 55′ in cooling 10°, while the latter cooled through the same interval in $36\frac{1}{2}'$; whence it appears that clothing does in some instances expedite the passage of heat out of a hot body instead of confining it. The only mode in which it is thought that this unexpected result can be accounted for, is by admitting that, as air is known to adhere with considerable obstinacy to the surfaces of certain solid bodies, the particles of air which were in immediate contact with the surface of the naked cylinder were so attached to the metal as to adhere to it with considerable force; and as confined air is known to be a very warm covering, it seems probable that the retardation of the cooling in this vessel was owing to that invisible covering, the air in contact with

the other vessel being absorbed, displaced, or in a great degree driven away by the colder covering of linen which closely embraced it.

Led on by this conjecture, several experiments were made with cylinders covered with one, two, or more coatings of glue, and of copal varnish; and the results, in fact, turned out favourable to the supposition, the cylinder with one coat of glue losing 10° of its heat in 43′, and that with two coatings in about 38′. With the copal also the cooling of the instrument became more and more rapid as the thickness of the varnish was increased; till, however, eight successive coatings having been applied, the cooling again became less rapid, and it was found that there was a maximum of thickness which produced the greatest effect. No probable reason is yet assigned for this limitation.

The next object was to find out what effect colour would produce in the experiments, and accordingly the cylinder with eight coatings of varnish was painted black; it was also painted in the same manner after all the varnish had been washed away; and lastly, it was likewise painted white: in each of these instances the cooling was accelerated by the paint, nearly in the same proportion as in the preceding experiments.

A nicety occurred now in the conducting of the experiments, which was thought to deserve particular attention: though the apparatus for confining the heat at the two flat ends of the cylinder was the best that could be contrived, yet it is not at all unlikely that some would escape in those directions, and thus occasion some fallacy in the results.

In order to investigate this point, a given number was previously assumed as the measure of the whole quantity of heat emitted by the whole instrument, without terminal coverings, during a certain period. The surface of the whole of the cylinder was then accurately measured, and also that of its vertical sides; and thence was inferred the proportion of heat that passed off through the sides of the instrument, and what proportion must have escaped through its uncovered ends. With these data it is easy to infer, from an experiment with the ends covered, what proportion of the heat, lost in the cooling, had escaped through the flat terminal surfaces when covered. In this manner it has been ascertained that, assuming the total of the loss of heat emitted by a cylinder, in a given time, for instance $55\frac{1}{2}'$, to be 10,000, the quantity that escapes through the vertical sides will be =7,015, and that which penetrates through the terminal sides and coverings =2,985.

Admitting these computations, it will now appear how an estimate may be made, what proportion of the heat lost in any other experiment, actually escaped through the vertical sides of the instrument: and as the quantity of the heat emitted may well be represented by the time of the emission, there can be no difficulty in substituting the velocity for the quantity; whence it is inferred, that in the experiment, for instance, when the sides of one of the cylinders were blackened, the velocity with which heat is given off from the naked

sides of a cylinder, is to the velocity with which it is given off by the blackened sides, as 5,654 is to 10,000 very nearly, the velocities being as the times of cooling inversely.

Before he proceeds further in his investigation, the author finds it necessary to describe an additional instrument which he contrived for measuring, or rather for discovering, those very small changes of temperature in bodies which are occasioned by the radiations of other neighbouring bodies that happen to be at a higher or a lower temperature. This instrument, which he calls a *Thermoscope*, consists of two glass balls joined with and opening into the two ends of a glass tube, which is bent in two places at right angles, so that the balls, when the instrument is erected, are at the same horizontal height. A small quantity (about one drop) of coloured spirits of wine was introduced into this tube before it was finally closed, which, when the temperature of the air in the whole tube and the two balls is equal, keeps its place nearly at the middle of the lower or horizontal part of the tube. No sooner, however, does this perfect equilibrium cease, than the drop will move towards the side that is least heated. A scale is here applied, which indicates the difference of the temperature of the air in the two sides of the tube, and in the respective balls. A vertical screen between the two balls prevents the radiance of a heated body approached to one of them from affecting the other. This instrument was found of so delicate a sensibility, that the naked hand presented to one of the balls at the distance of several inches, would put the spirit of wine in motion, and the approach of a person at some feet from it would immediately affect it.

A conjecture is now proposed, which this instrument was intended to elucidate and probably confirm. There being great reason to conclude, that all the heat which a hot body loses when exposed to the air, is not given off to the air which comes into contact with it, but that a large proportion of it escapes in rays which do not heat the transparent medium through which they pass, but, like the rays of light, generate heat only then and there where they are intercepted and absorbed; it may hence be concluded, that in general, as has been in particular observed in the foregoing experiments, the cooling of the instruments is in fact promoted by the coverings applied to their surfaces; those coverings, considered as substances on which the rays impinge, being the means which in some way or other accelerate, or at least facilitate, the emission of calorific rays from the hot surfaces.

The first experiment, which has thrown some light upon this subject, was made with two brass cylinders equally heated, but in one of which one of the flat surfaces had been blackened, while the whole of the other cylinder was left in its polished state. The black surface of the one, and one of the bright surfaces of the other, were presented to the two opposite balls of the thermoscope, each to each, and at equal distances. Here the little column of spirit of wine in the tube beneath was instantly driven out of its place by the superior action of the blackened surface, and did not return to its former

station till the effect was compensated by proportionably altering the distances of the heated cylinders from the balls. In some further experiments, instead of blackening one of the flat surfaces of one of the cylinders, the other coverings used in the foregoing trials were applied, and the results were such as might have been expected. They all tended to prove that different bodies, or rather different surfaces, emit heat not by any conducting power in themselves, or in the surrounding bodies, but by a power which is here called *radiation,* the nature of which had hitherto escaped our notice.

Several experiments were next made with heated cylinders of different metals, but the results proved that all metals give off heat with the same facility, or rather with the same celerity. May not this, it is asked, be owing to their being all equally wanting in transparency? And does not this afford us a strong presumption that heat is in all cases excited and communicated by means of *radiations,* or as they may more properly be called *undulations?*

Before these questions can be solved, another and a very important point in this inquiry must be decided, viz. whether bodies are cooled in consequence of the rays they emit, or by those they receive? Our author was manifestly led to this problem by the celebrated experiment of Prof. Pictet, from which it appears that rays or emanations which (like light) may be concentrated by concave mirrors, proceed from cold bodies; and that these rays when so concentrated, are capable of affecting an air thermometer in a manner perfectly perceptible. The first experiment on this subject was to ascertain the existence of these cold emanations universally; and this being successfully effected, it is proved by other processes, the detail of which would far exceed our bounds, that the radiation of cold as well as of hot bodies being established, the rays which proceed from cold bodies have likewise the power of *generating cold* in warmer bodies which are exposed to their influence.

The object of another set of experiments was to ascertain whether all cold bodies at the same temperature emit the same quantity of rays; or whether (as is the case with respect to the calorific rays emitted by hot bodies,) some substances emit more of them than others. Here it was a great gratification to the author to find in the first experiment that the frigorific rays, from a blackened metallic surface, were much more powerful in generating cold than those which proceeded from a similar metallic surface of exactly the same temperature, but without any coating.

Observing that the approach of the hand to one of the balls of the thermoscope affected the indications very sensibly and rapidly, it occurred that perhaps animal substances emit both calorific and frigorific rays more copiously than other substances, and that probably living animal bodies emit them in still greater abundance than dead animal matter. This was confirmed by a very conclusive experiment, in which one of the metallic surfaces was covered with goldbeater's skin, and which surface emitted at least twenty-five times more calorific rays than a naked surface. The frigorific rays from the animal

substance were likewise found to be much more efficacious in producing cold than those from the polished surface; though in what proportion could not be ascertained with any degree of accuracy. In general, however, there is every reason to conclude that at equal *intervals of temperature*, the rays which generate cold are just as real and just as intense as those which generate heat, or that their actions are equally powerful in changing the temperature of neighbouring bodies.

Our author, ever doubtful of the existence of the *caloric* of the modern chemists, thinks himself authorized here to throw out the following observation respecting that favourite hypothesis. On a supposition that caloric has a real existence, and that heat or an increase of temperature in any body is caused by an *accumulation* of that substance in such body, the reflection of cold would indeed be impossible; and to maintain its reality must to all unprejudiced minds appear an absurdity.

By further experiments it is proved that all those circumstances which are favourable to the copious emission of calorific rays from the surfaces of hot bodies, are equally favourable to the copious emission of frigorific rays from such bodies when they are cold. That, on the other hand, those substances which part with heat with the greatest facility or celerity, are those which acquire it also most readily. Also that an animal substance, for instance goldbeater's skin, will throw off more heat, and be more sensibly affected by the frigorific rays of colder bodies when blackened, than when they are of their natural colour. This latter fact is applied as a proof of the great utility of the inhabitants of hot climates being of a black colour; and it is suggested that Europeans might find some relief by availing themselves of this circumstance when they visit the torrid zone. It is also surmised that the custom of savages inhabiting cold countries, of besmearing their bodies with oil or other unctuous matter, may have its utility by enabling their skins to reflect the parching frigorific rays that reach them from the atmosphere.

Another subject, which is here minutely investigated, is to ascertain what proportion of the heat emitted by a hot body is acquired or retained by the circumambient air; and the result yielded by several experiments and calculations turns out, rather unexpectedly, that this proportion is so little as $\frac{1}{27}$th of the whole. And it is also proved that a heated body, of a globular form, being suspended in the centre of another larger thin hollow sphere, at the same temperature as the air and the walls of the room, the vicinity of the two surfaces will sensibly retard the cooling of the hot body; and that if instead of one there be a number of thin concentric spheres of different diameters, the retardation of the cooling will be still greater. Combining with this the results of some former experiments, from which it appears that the cooling will be slower when the opposite surfaces are bright, than when they are unpolished or blackened, some inferences are derived concerning the warmth of different substances used as clothing, their effect in this respect, consistently with

the hypothesis of radiation, depending very much on the polish of their surfaces. Thus if those substances which supply the warmest coverings, such as furs, feathers, silk, &c. be viewed through a microscope, we shall find the surfaces of their fibres or minute laminæ not only smooth, but also very highly polished: and those substances will be warmest which excel in these respects, the fine white shining fur of a Russian hare being much warmer than coarse hair; and fine silk, as spun by the silk-worm, being preferable for warmth to the same silk twisted together into coarse threads.

A considerable part of the paper is now bestowed on the theory of heat, which the author attempts to deduce from the foregoing facts and observations. Heat and cold, he says, like fast and slow, are mere relative terms; and as there is no relation between motion and rest, so there can be none between any degree of heat and absolute cold, or a total privation of heat. It has long been thought, and it appears more and more probable, that *motion* is an essential quality inherent in all matter: this is illustrated by many examples; and by applying the analogy above given, and the observations since brought forward, there seems every reason to believe that, without having recourse to any specific element, all the phenomena of heat may be accounted for by the simple operations of *motion;* or that motion, in fact, constitutes the heat or temperature of sensible bodies.

It will no doubt occur that this theory will hardly account for the effects of frigorific rays; but this objection is answered by the observation, that as the rapid undulations occasioned in the surrounding ethereal fluid by the swift vibrations of a heated body will act as calorific rays on the neighbouring colder solid bodies; so the slower undulations occasioned by the vibrations of a cold body, will act as frigorific rays on neighbouring bodies of a higher temperature; and that these reciprocal actions will continue, but with decreasing intensity, till the two bodies have acquired the same degree of temperature, or until their vibrations have become isochronous.

According to this hypothesis, *cold* can with no more propriety be considered as the absence of *heat,* than a low or grave sound can be considered as the absence of a higher or more acute note; and the admission of rays which generate cold involves no absurdity, and creates no confusion of ideas.

As this theory, however, entirely supersedes the hypothesis of the calorific element, of late so much resorted to, it may be imagined that the author would not discuss the controversy in a slight or superficial manner; and accordingly many pages are here dedicated to this intricate and abstruse disquisition.

Among other important points, it was necessary to reconcile solidity, hardness, and elasticity, with the incessant motion he ascribes to the constituent particles of matter, and to obviate the objection founded on a supposition that there is not room sufficient for this motion. What increases the perplexity is, that, admitting the changes of temperature in bodies to be the effect of the calorific and frigorific radiations above described, a particular nicety will be required to

distinguish between the effects of those simultaneous operations, and of ascertaining their relative intensities. A hot body, A for instance, heats a neighbouring colder body B, by its calorific radiations; but B emits at the same time frigorific radiations, which contribute to lower the temperature of A; nor is it clear that both these bodies, especially if they have polished surfaces, will not reciprocally, and perhaps repeatedly, reflect those incident rays, and that those rays will not be refracted by the media through which they pass, and be concentrated or expanded by the shapes of the reflecting surfaces, and thus create a combination of effects, which it will require much labour and ingenuity to unravel.

As it is impossible for us within our narrow limits to do justice to the connected series of observations and arguments here adduced, we shall refer those who wish for more ample information on the subject to the paper itself; and this the rather, that we may dwell more largely upon the practical uses that may be derived from a knowledge of the facts which the author now considers as fully established.

In all cases where it is intended to preserve the heat of any substance which is confined in a metallic vessel, it will greatly contribute to that end if the external surface of that vessel be kept very clean and bright; but if the object be to cool anything quickly in such a vessel, its external surface should be painted, or coloured with some of those substances which have been found to emit calorific radiations in abundance. Hence the sides of kitchen utensils should be kept bright, in order to confine the heat; while their bottoms should be blackened, in order that their contents may be made to boil sooner, and with a less expense of fuel.

Brewers, it seems, are mistaken when they employ broad shallow vessels, or flats, as they call them, of metal for cooling their wort. Wooden flats, it appears, ought in every respect to have the preference.

In all cases when metallic tubes, filled with steam, are used for warming rooms or hot-houses, the external surface of those tubes should be painted, or covered with some substance which facilitates the emission of calorific rays. Where, on the other hand, tubes are intended to convey hot steam from one place to another, they should be kept very clean and bright. This applies also to the cylinders of steam-engines, and the principal tubes used in that machine.

Gardeners should advert to the circumstance, that if walls painted black acquire heat faster when exposed to the sun's direct rays, they likewise cool much faster during the night, and in the shade when the weather is cold.

Black cloths are known to be very warm in the sun; but they are far from being so in the shade, especially in cold weather, when the temperature of the air is below that of the surface of the skin.

It having been shown that the warmth of clothing depends much on the *polish* of the surface of the substance of which it is made, we may conclude that in choosing the colour of our winter garments, those dyes should be avoided which tend most to destroy that polish.

Hence there is reason to think that, contrary to the general opinion, white garments are warmer than any other in cold weather; and indeed if they are well calculated to reflect calorific rays in summer, they ought to be equally well calculated to reflect those frigorific rays by which we are annoyed in winter. Fur garments have been found by experience to be much warmer in cold weather, when worn with the hair outwards, than when it is turned inwards.

This is alleged as a proof that we are kept warm by our clothing not so much by confining the heat of our bodies, as by repelling those frigorific rays which tend to cool us. The fur of several delicate animals we know becomes white in winter in cold countries; and bears which inhabit the polar regions are likewise known to be white in all seasons. Now if, in fact, as there is great reason to believe, white is the colour most favourable to the reflection of calorific and frigorific rays, it must be acknowledged that these animals have been greatly favoured in having a clothing assigned them so well adapted to their local circumstances.

The excessive cold which is known to prevail, in all seasons, on the tops of high mountains, and the frosts at night which frequently take place on the surface of the plains below, seem to indicate that frigorific rays arrive continually at the surface of the earth from every part of the heavens; and it is no doubt by the action of these rays that our planet is continually cooled, and enabled to preserve the same mean temperature for ages, notwithstanding the immense quantities of heat that are generated at its surface by the continual action of the solar rays. The action of these frigorific nocturnal rays will likewise justify the inhabitants of hot climates, who, in order to be more cool during their hours of rest, remove their beds in summer to the tops of their houses.

Experiments and Observations on the Motion of the Sap in Trees. In a Letter from Thomas Andrew Knight, *Esq. to the Right Hon. Sir* Joseph Banks, *Bart. K.B. P.R.S.* Read February 16, 1804. [*Phil. Trans.* 1804, *p.* 183.]

Some experiments are here described, the tendency of which is to prove, what the author had advanced as a conjecture in a former communication, that the vessels of the bark which pass from the leaves to the roots, are in their organization better calculated to carry the fluids they contain towards the roots than in the opposite direction.

In the first of these experiments several strong horizontal shoots of vines were depressed about their middle; and at that part, buried in the mould, contained in pots about ten inches in diameter: after some months of vegetation, when the shoots had nearly filled the pots with roots, they were separated from the parent stock, having at each side above the earth a certain length of the layer, with at least one bud upon each. The end towards the stock was called the inverted, and the other the proper end of the layer. If the author's